Enabling Entry Technologies for Ice Giant Missions

E. Venkatapathy[1*], A. Austin[2], A. Cassell[1], D. Ellerby[1], J. Elliott[2], P. Gage[3], M. Lobbia[2], A. Nelessen[2], D. Prabhu[4], B. Strauss[2], and P. Wercinsk[1],
[1] NASA Ames Research Center, [2] Jet Propulsion Laboratory, California Institute of Technology, [3] Neerim Corp., [4] AMA Inc.

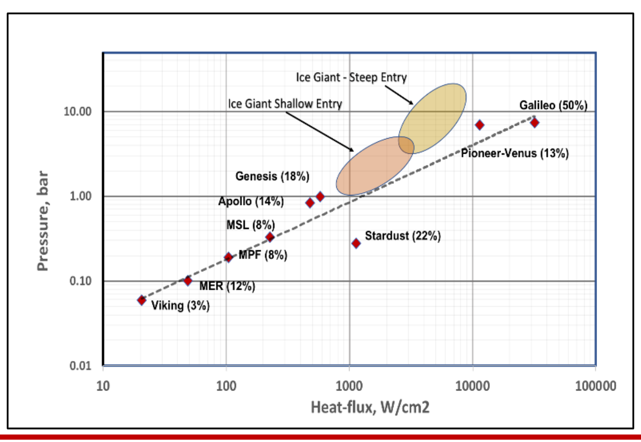
Enabling Simultaneous Orbital and *In Situ* Measurements

- The highest priority science goals for Ice Giant missions are: 1) Interior structure of the Planet, and 2) Bulk composition that includes isotopes and noble gases.
- The interaction between the planetary interior and the atmosphere requires sustained global measurements. Noble gas and Isotope measurements require in situ measurement. Drag modulated aerocapture utilizing ADEPT offers more mass delivered to the Ice Giants than with propulsive orbit insertion.
- The Galileo Probe entered at a 'hot' spot which created interpretation challenges. Juno is providing valuable orbital measurements, but without in situ measurements the story is incomplete. Planetary scientists interested in Ice Giant missions should perform mission design studies with these new Entry System technologies to assess the feasibility within the context of the international collaboration framework.
- A mission architecture that includes probe(s) along with an orbiting spacecraft can deploy the probes at the desired location while taking simultaneous measurements from orbit to provide invaluable data that can correlate both global and local measurements.
- Entry System Technologies currently being developed by NASA are poised to enable missions that position the Orbiter & Probes through drag modulated aerocapture (ADEPT), and HEEET enables the Probes to survive the extreme environments encountered for entry into the atmospheric interior.

Heatshield for Extreme Entry Environment Technology (HEEET) – Enabling Technology Ready for Ice Giant Probe Missions

Probes and Entry Systems

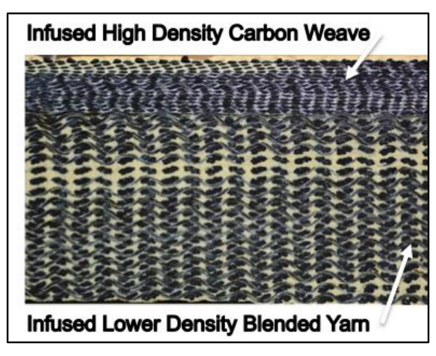
- NASA's Ice Giant Planets Study Team (2015) prioritized and recommended **an orbiter with probe mission** (2023 -2032).
- Extreme heating and pressure loads during entry require robust and capable thermal protection system through the entry phase.



What is HEEET?

- HEEET is an **integrally 3-D woven, dual-layer, ablative heat-shield system**.
- **Outer layer**, high density carbon, is specifically designed to be robust against external environment (heat-flux, pressure, shear, etc.)
- **Inner layer**, composite phenolic and carbon yarn at lower density, is insulative.
- Both layers can be tailored in thickness and yarn selection.
  - Mission design is constrained by loom limits on total thickness of TPS.
- The tile arrangement requires seams.
  - The seam material is the same as acreage but is made compliant to accommodate relative displacement of tiles, for system robustness.
- Highly scalable by increasing number of tiles.

What is HEEET?

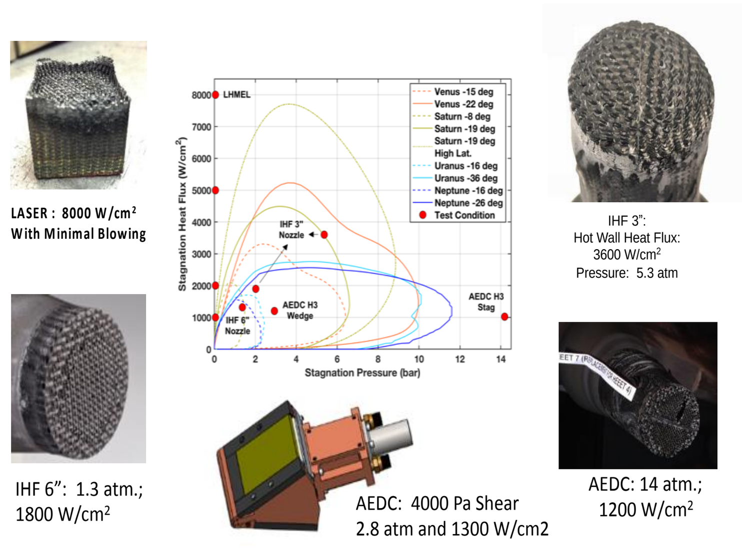


Individual parts (tiles and gap-fillers) use a newly-developed material: integrally woven layers of Carbon and blended yarns. Woven material is cut and formed to near-net shape, infused, and machined to final shape

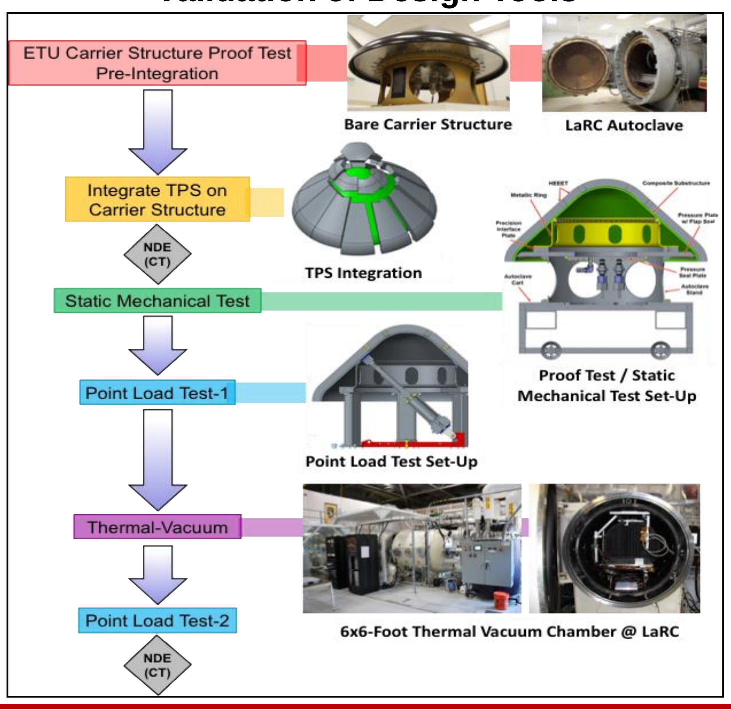
HEEET is more than individual parts: complete heatshield assembly demonstrated through integration of several rings of tiles and gap-fillers.

Thermal Testing at Extreme Conditions

- Dual layers including integrated seam have been tested at extreme conditions, without any sign of failure.



Successful Integrated System Testing and Validation of Design Tools



HEEET vs Heritage Carbon Phenolic

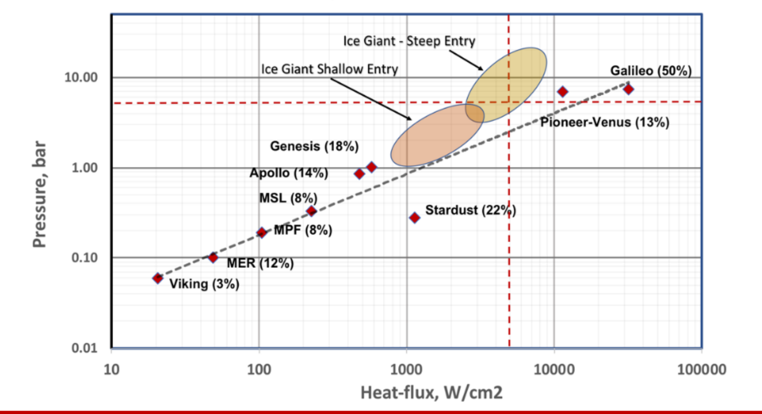
- HEEET is more mass efficient than carbon phenolic
  - Pre-decadal Ice Giant Study indicates ~50% mass reduction for multiple point designs.

Planet	Uranus		Neptune		
Entry Parameters	Design #1	Design #2	Design #3	Design #4	Design #5
Hyperbolic excess velocity (km/s)	9.91	8.41	12.32	11.3	11.4
Inertial entry velocity (km/s)	23.1	22.52	26.12	25.73	25.72
Inertial entry flight path angle (deg)	-35	-30	-34	-20	-16
Inertial heading angle (deg)	-5.82	-20.02	-99.1	-84.26	-86.45
Latitude (deg)	-9.22	-5.63	-1.42	24.8	22.64
Max deceleration (g load)	216.65	164.75	454.91	208.71	124.51
Stg pressure (bar)	12	9	25	11.5	6.8
Peak convective heat flux (W/cm²)	3456	2498	9368.5	5362.4	4311
Peak radiative heat flux (W/cm²)	0	0	265.68	99.12	68.2
Peak total heat flux (W/cm²)	3456	2498	9634	5462	4379
Total heat load (J/cm²)	43572	41114	81476	109671	133874
HEEET TPS mass (kg)	*Not computed*	29	*Not computed*	39	47
HCP TPS mass (kg)		60		73	88
Feasible design	Maybe	Yes	No	Maybe	Maybe

- Updates to the IGS study (2017) provide guidance for design closure with fully matured HEEET system.
- Ref: Space Science Review paper accepted for publication.

Weaving and Ground Test Capability Limitations and Mission Constraints

- Ground testing and weaving capability limitations require that Neptune and Uranus missions should enter at shallow angles and employ entry system with blunter nose than heritage shapes
- Resulting g-load (< 250 g) beneficial for science instrument development.



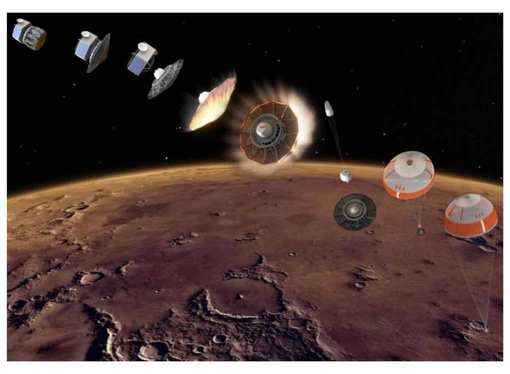
Remarks

- NASA developed HEEET in anticipation of extreme entry environment *in situ* missions such as Ice Giants.
- Technology Readiness Assessment of TRL 6, confirmed by Independent Review Board.
- HEEET is offered as an incentivized Technology by NASA under NF and Discovery.
- Ice Giant missions, both direct and entry from Orbit, need HEEET
- No other options are currently available.
- Mars Sample Return Mission's Earth Entry Vehicle has baselined a variant of HEEET.
- HEEET capability will be sustained for missions in the coming decade.

Adaptive Deployable Entry and Placement Technology (ADEPT)

What is ADEPT ?

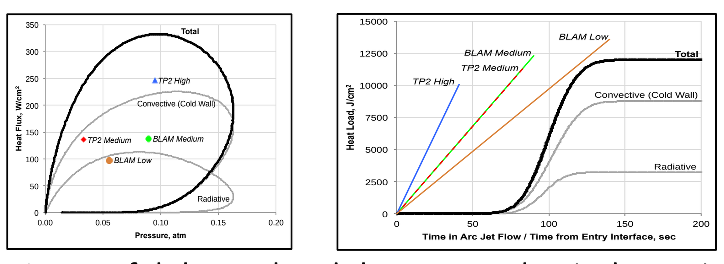
- ADEPT is a novel, foldable and deployable entry system, like an umbrella, that allows for large deployed surface during entry to lower entry conditions.
- 3-D woven carbon fabric allows for folding and unfolding and is capable of withstanding thermal and mechanical entry loads.



3D Carbon Weave

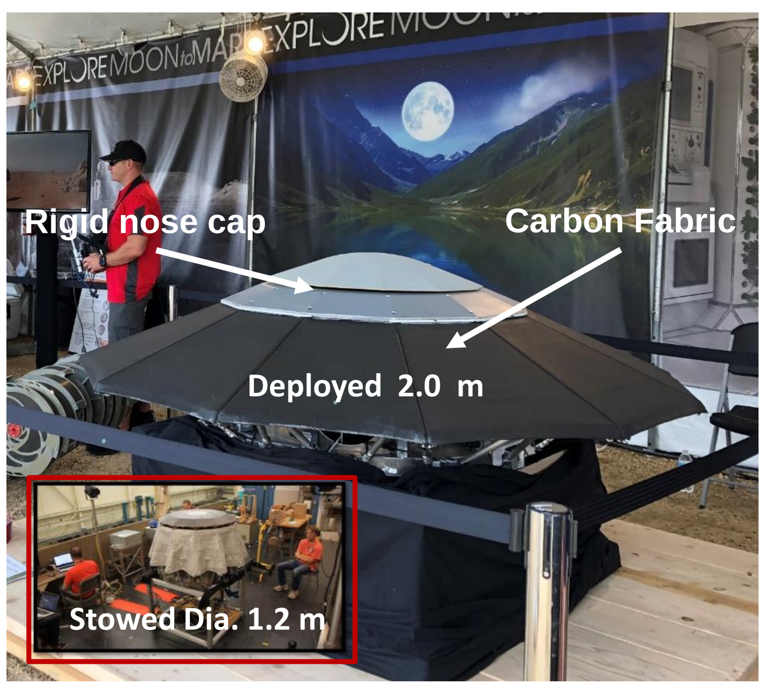
Key Component of ADEPT – Multifunctional Carbon Fabric

- Multi-layer, 3-D woven carbon fabric is the key and critical component. The foldable and deployable fabric is both the decelerator surface and also protects the scientific payload from entry heating.
- Carbon fabric has been tested at moderate conditions and testing in the future will cover relevant high conditions.

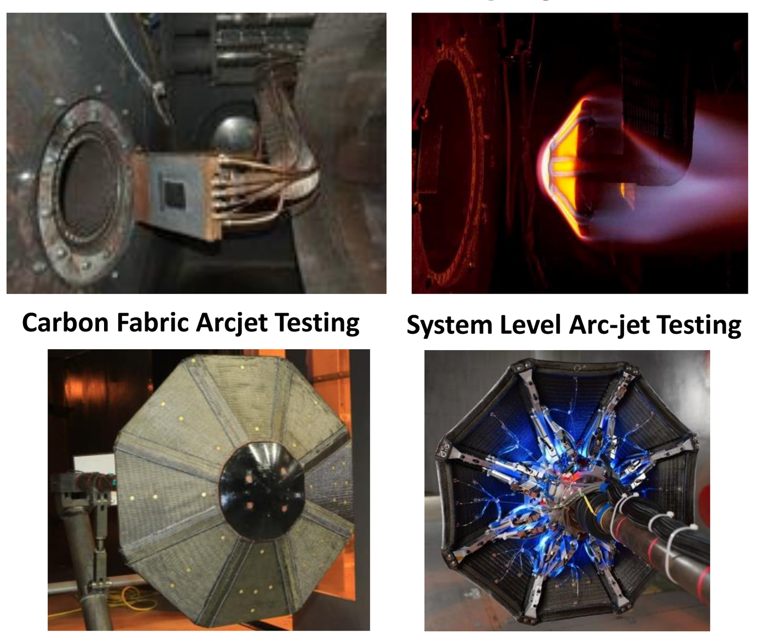


- Successful thermal and thermo-mechanical tests in the arc jet provided performance confidence.

2 m Diameter Deployment Testing



Aerothermodynamic and Aerodynamic Ground Test Campaigns

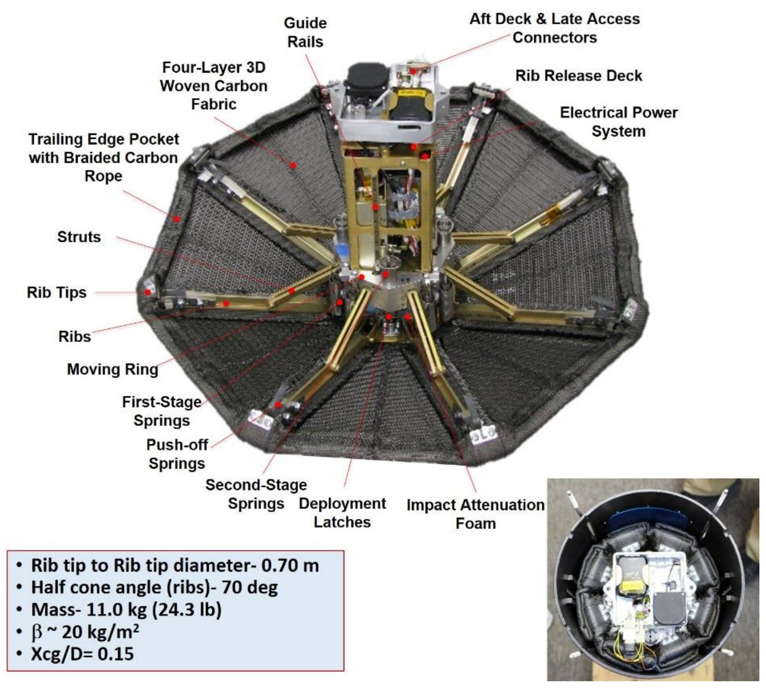


Carbon Fabric Arcjet Testing

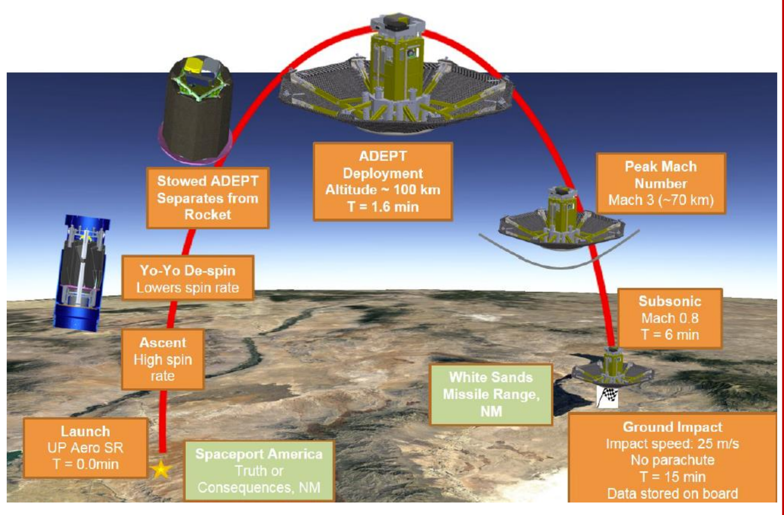
System Level Arc-jet Testing

Aerodynamic Loading Wind-tunnel Testing

Sounding Rocket Flight Test Article

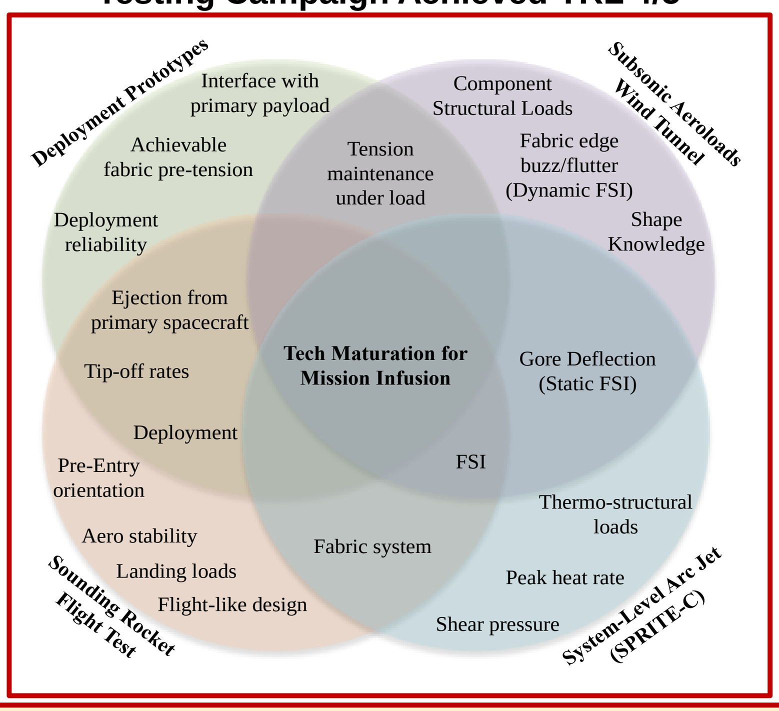


Sounding Rocket Flight Test Profile



- SR-1 (Flight test on Sept 12, 2018) demonstrated packaging, in-space deployment and provided aerodynamic data for validation. ADEPT is stable through supersonic and subsonic (M < 0.4) as expected

Suborbital Flight & Comprehensive Ground Testing Campaign Achieved TRL 4/5



Remarks

- ADEPT, a novel entry system has been matured to a TRL (4/5) for small satellite scale missions (< 2m dia).
- 3-D Woven carbon fabric manufacturing can support ADEPT deployed diameters up to ~20 m.
- Carbon fabric system technology has been demonstrated to perform well under relevant thermostructural loading conditions.
- ADEPT is seeking to utilize secondary payload technology demonstration opportunities to further increase TRL for mission infusion.

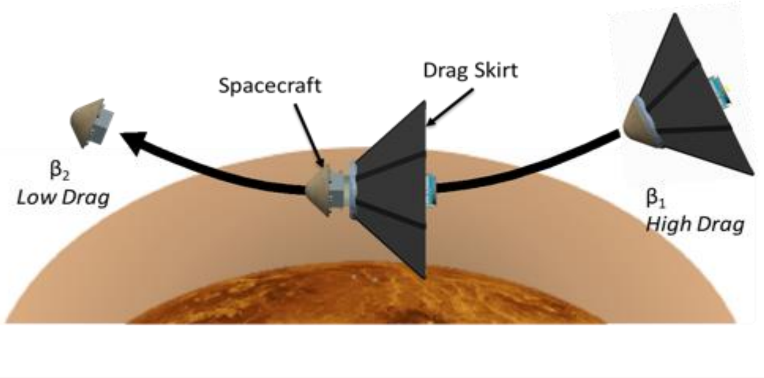
Heatshield for Extreme Entry Environment Technology (HEEET) – Enabling Technology Ready for Ice Giant Probe Missions

Why Aerocapture? What is Drag Modulated Aerocapture?

- Aerocapture can provide greater mass efficiency and faster trip times, compared to propulsive orbit insertion, especially for Ice Giant Missions.
- In drag modulated aerocapture, the drag of the entry system is modified to achieve the desired velocity reduction for capture into orbit.
  - A deployed drag surface is ejected once velocity reduction is achieved during a single atmospheric pass

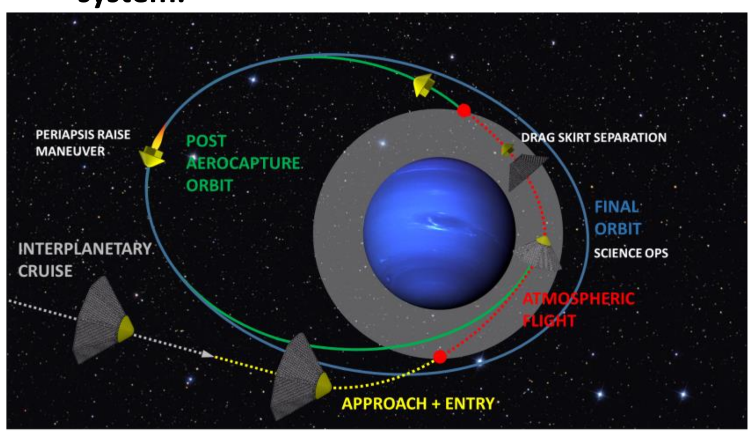
Drag Modulated Aerocapture with ADEPT

- **The ADEPT drag skirt is integrated with the spacecraft, deployed prior to entry. The drag skirt is separated during aerocapture once the desired velocity reduction is achieved.**
- **Simple and scalable**



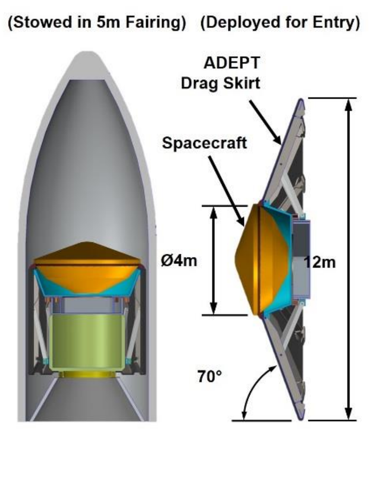
Ice Giant Mission Concepts with DMA

- **Preliminary studies performed by JPL for both Uranus and Neptune show DMA can reduce trip time and achieve mass efficient orbit insertion for a range of payload masses, including orbiter, probe(s) and landers to the moons in the system.**



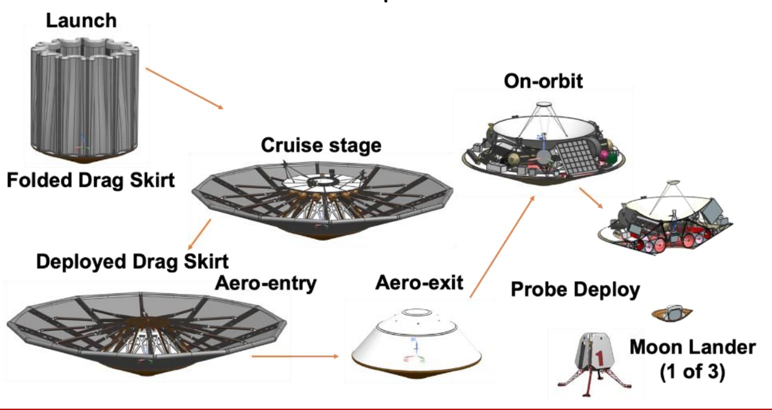
Notional Uranus DMA Concept Utilizing ADEPT

- Using Falcon Heavy launch with Jupiter flyby and radioisotope electric propulsion, the spacecraft arrives at Uranus in ~9 years.
- Chemical propulsion feasible for a (12-13) year flight. Faster arrival will require **a delta-v of ~5 km/s** (for a ~9 year flight), likely not possible.
- **Aerocapture can shorten flight time for science mission by 3-4 years.**



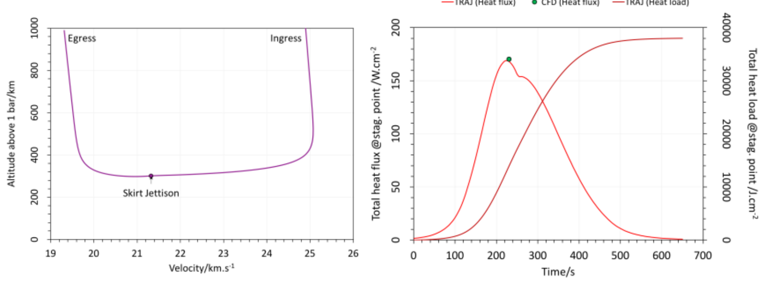
Drag Modulated Aerocapture with ADEPT

- DMA allowed the mission design to achieve high priority science goals and additional stretch goals
  - Orbiter and a Shallow Probe delivered post-aerocapture
  - Also included Deep Probe and 3 Landers

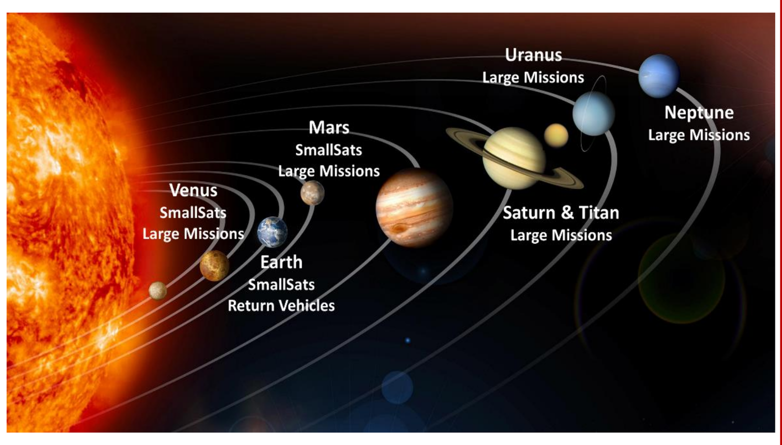


Preliminary Trajectory & Stagnation Point Aerothermal Environments at Neptune

- 12 m (dia.) ADEPT skirt deploys a 4 m (dia.) spacecraft (1800 kg) Entry mass = 4000 kg,
- Entry Vel. (inert.) = 28 km/s; EFPA of. -10.9°; skirt jettison at 252 s and payload achieves an apoapsis ≈ 430000 km
- Peak aerothermal conditions: Pressure < 0.03 atm., Heat Flux < 200 W/cm², 40,000 J/cm². and peak deceleration < 70 m/s² (< 7g)



DMA Capability is Scalable and Applicable Across the Solar System



DMA with ADEPT has the potential to deliver SmallSats and Large Missions to Venus and Mars, and Large missions to Saturn, Titan, Uranus and Neptune

Remarks

- ADEPT and Drag Modulated Aerocapture are currently being matured in a partnership between NASA Ames, JPL and Cal Poly Boulder.
- The goal is an earth-based flight demonstration for DMA in the next few years to be ready for Ice Giant and Venus missions.
- Venus DMA mission will focus on a rideshare SmallSat mission opportunity to deliver science.
- Ice Giant missions will focus on delivering a spacecraft with probes and landers, faster and more efficiently, enabling greater science.

Concluding Remarks

- The coming decade presents a once in a generation opportunity for exploring the Ice Giants.
- The HEEET & ADEPT technologies are nearing maturity and should be considered by mission planners to enhance science return.
- Drag modulated aerocapture utilizing ADEPT offers more mass delivered to the Ice Giants than with propulsive orbit insertion.
- If the Tempest (or similar) mission concept can be performed within the cost & risk constraints, it will provide extremely valuable and unprecedented scientific data.
- Planetary scientists interested in Ice Giant missions should perform mission design studies with these new Entry System technologies to assess the feasibility within the context of the international collaboration framework.